A MICROWAVE RADIO RELAY SYSTEM

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By

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INTRODUCTION

A microwave radio relay system is a communications system whereby information is transmitted from one location to another via radio frequency energy.

This thesis is concerned with the installation and testing of such a system on the University of Arkansas campus between the Science Engineering Building and the Engineering Building.

The system has been installed and tested for proper operation.

MICROWAVE SYSTEM

The microwave region of the electromagnetic spectrum is commonly taken to start near 1 Gc* and extends upward to about 100 Gc. These are not intended to be considered as fixed boundaries but as approximations to assist in visualizing the portion of the electromagnetic spectrum of interest. This is the region in which distributed-element circuits are used rather than lumped-element circuits that are used at lower frequencies.

There are two features that are characteristic of microwave circuits. They are:

1. The physical size of the circuit elements is comparable with the wavelength involved.
2. The electromagnetic fields are totally confined within conducting walls, except where it is desired that energy be radiated into space.

The Motorola "Research" Line microwave equipment is the type installed. This type provides one hundred milliwatts of radio frequency energy output. It is designed to operate in the 5925-7395 megacycle portion of the radio frequency spectrum. The specific frequencies for this unit are 6925 and 6415 megacycles. At each of the

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*The IEC recently recommended that hertz be used to designate cycles per second. However, since this thesis pertains to equipment with technical manuals published prior to the IEC action, nomenclature throughout the thesis is in cycles per second.

two locations, the radio frequency (RF) unit and its associated power supply are mounted in an outdoor weatherproof housing consisting of a self-supporting frame and two rib-reinforced doors (Reference Plate 1).

The RF unit plumbing consists of two functional sections, transmitting and receiving, which are joined in a common connection to the antenna. The transmitting section contains a klystron tube which generates the microwave carrier. This carrier is frequency modulated by varying the repeller voltage of the transmitter klystron with the modulating signal. Provisions are made to sample the transmitted wave for frequency and power. A phase shifter is provided to cause the transmitting section to appear as a high impedance to the received energy, thus causing it to enter the receiver portion of the waveguide. The transmitter energy flows past a "wye" section and through the top flange of the RF plumbing to the antenna. Pre-selection cavities prevent the transmitter energy from entering the receiver section. Figure I depicts this section of the system.

The superheterodyne principle is used in the receiving section to demodulate the incoming microwave carrier frequency. This carrier flows through the "wye" section to the receiving section of the RF plumbing where it is fed into a crystal mixer concurrently with a local oscillator signal generated by another klystron. The output from the crystal mixer is a 75 megacycle difference frequency between the local oscillator and receiver carrier frequencies. The pre-selection cavities mentioned in the previous paragraph have an overall bandwidth of approximately seventeen megacycles. The response of

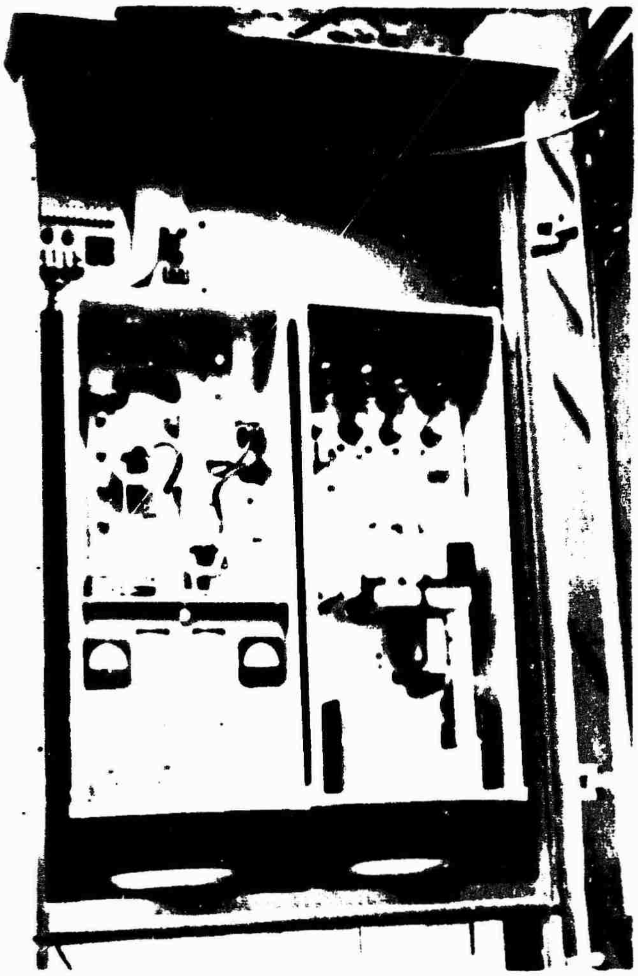
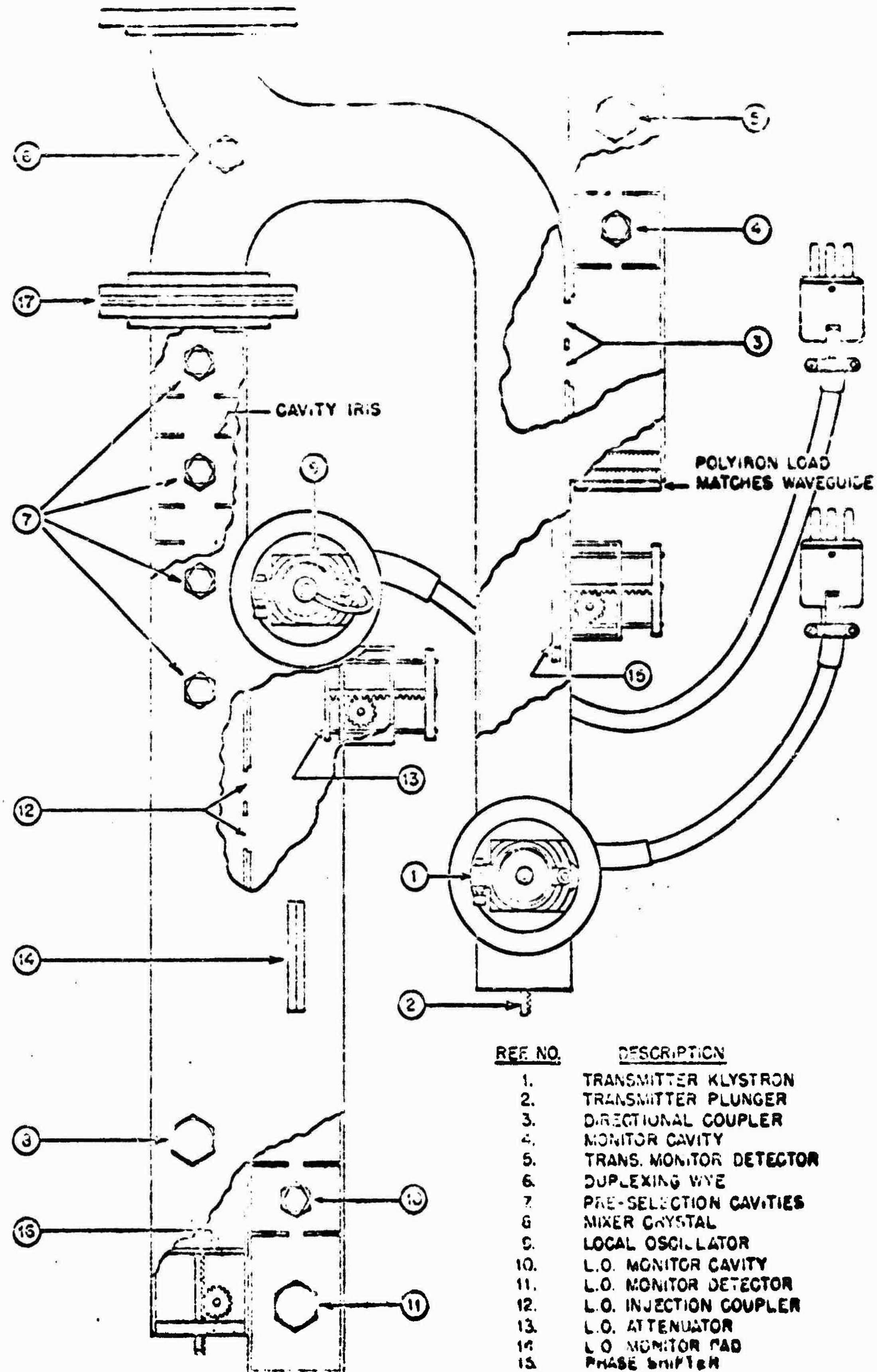


PLATE 1   RF UNIT



REF NO.	DESCRIPTION
1.	TRANSMITTER KLYSTRON
2.	TRANSMITTER PLUNGER
3.	DIRECTIONAL COUPLER
4.	MONITOR CAVITY
5.	TRANS. MONITOR DETECTOR
6.	DUPLEXING WYE
7.	PRE-SELECTION CAVITIES
8.	MIXER CRYSTAL
9.	LOCAL OSCILLATOR
10.	L.O. MONITOR CAVITY
11.	L.O. MONITOR DETECTOR
12.	L.O. INJECTION COUPLER
13.	L.O. ATTENUATOR
14.	L.O. MONITOR PAD
15.	PHASE SHIFTER
16.	MIXER PLUNGER
17.	WAVEGUIDE SPACERS

FIGURE 1 RF UNIT PLUMBING

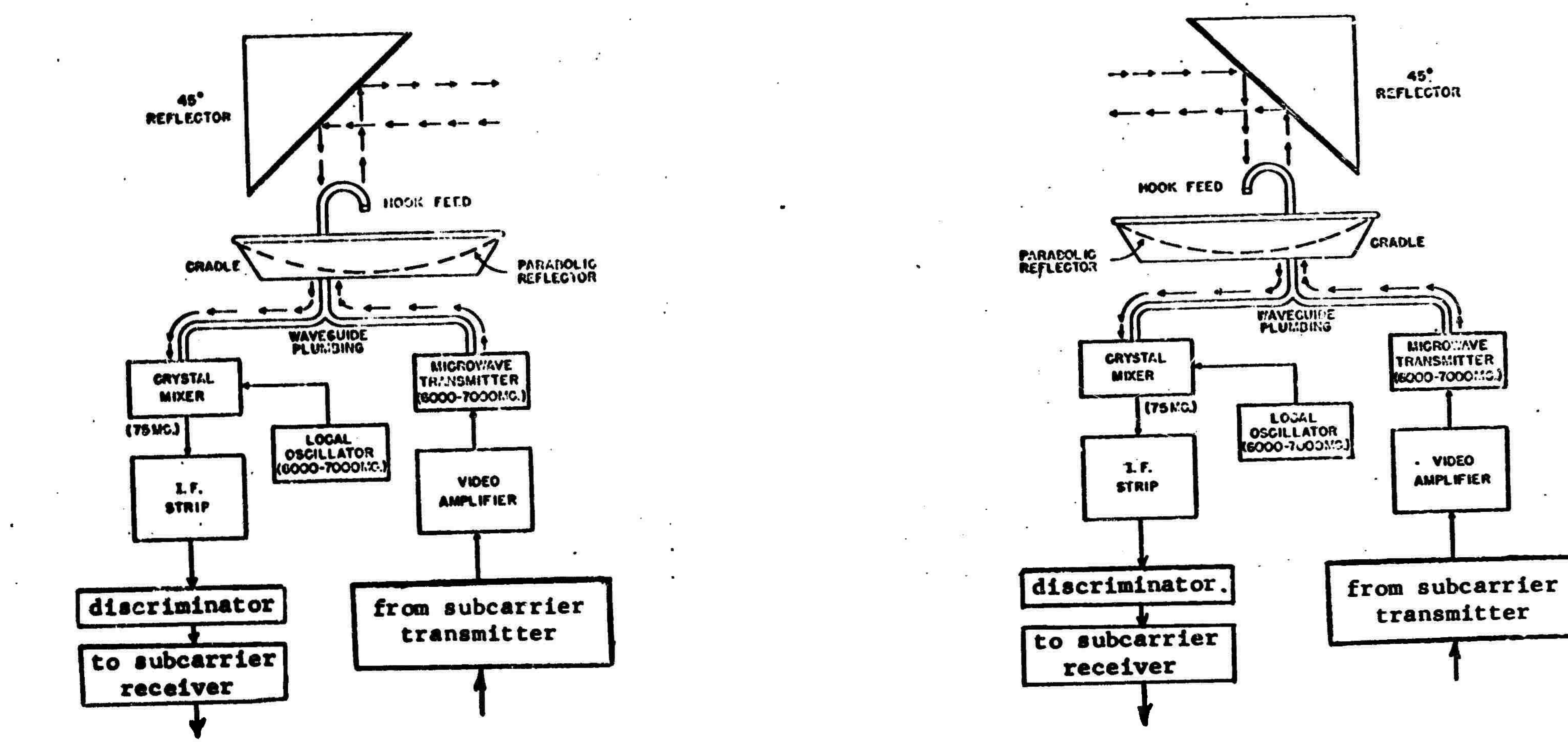


FIGURE 2 MICROWAVE SIGNAL FLOW DIAGRAM

these cavities drops sharply for frequencies outside their passband, thus preventing interference from other frequencies that may be present.

The 75 megacycle output frequency is then amplified and demodulated to obtain the subcarrier output frequencies which are carried by a 75 ohm coaxial cable to the subcarrier receiver frames.

The microwave carrier is frequency modulated approximately plus or minus four megacycles by varying the klystron repeller voltage. This equipment was designed to be modulated by a composite signal formed by combining the outputs from a service channel subcarrier transmitter operating at 5.4 megacycles, a program audio subcarrier transmitter operating at 5.0 megacycles, and a video signal from 30 cycles to 4.0 megacycles. This composite signal is amplified in a video amplifier and applied to the repeller plate of the transmitter klystron. The equipment presently available includes only the video signal channel which can handle all frequencies between 30 cycles and 5.4 megacycles. Refer to Figure 2 for a signal flow diagram.

ANTENNA

A single antenna is used for simultaneous, continuous transmission and reception of the microwave signals. The basic antenna assembly consists of a waveguide horn radiating into a one meter parabolic reflector mounted directly above the RF unit. This antenna array has a gain of 35 decibels (3200 times power), a beamwidth of 3.5 degrees between one-half power points in both the horizontal and vertical planes, and a system voltage standing wave-ratio less than 1.1 at the specified frequency.

The antenna is designed to direct the energy upward to a reflector mounted at a 45 degree angle above the antenna or to radiate the energy horizontally direct into the other unit. The reflector is used to bounce the signal over any obstacles that would otherwise be in the line-of-sight between the units.

The installation on the Science Engineering Building uses the reflector method to bounce the energy over an exterior wall located between the two terminal points. This was accomplished by designing and constructing a mounting system to support the reflector from below rather than using the upper mount and tower configuration as originally designed. Plate 2 shows this installation.

The installation on the Engineering Building did not present this problem, so the antenna was mounted to direct the microwave energy directly toward the reflector on the Science and Engineering Center.

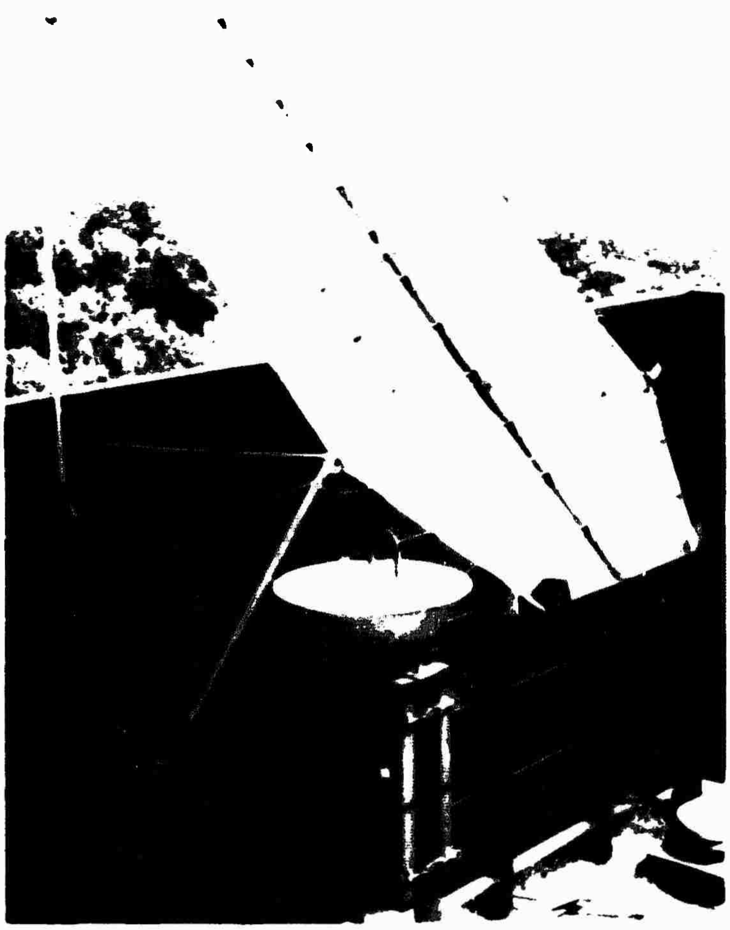


PLATE 2 SCIENCE ENGINEERING BUILDING INSTALLATION

Plate 3 depicts this installation.

Both units are mounted on wooden platforms to prevent roof damage and are adequately guyed and braced to permit continuous operation as a permanent fixed facility.

PLATE 3 ENGINEERING BUILDING INSTALLATION

SUBCARRIER SYSTEM

This system provides facilities for the transmission and reception of telephone, telegraph, telemetering, and supervisory control signals over a microwave system. The multiplex equipment consists of Motorola "Research" Line FM subcarrier transmitters and receivers with associated mounting frames, voice terminals, power supplies, and a chassis interconnecting cable kit. A "channel" consists of one transmitter and one receiver with their associated equipment at each terminal of the microwave relay link. Any number of such channels may be used simultaneously up to a maximum of twelve with this particular equipment. Plate 4 shows this equipment.

Subcarrier channel frequencies range from 150 kilocycles to 1000 kilocycles, with each channel having a definite bandwidth calculated on the basis of obtaining the best signal-to-noise ratio. Each channel in this system is a separate, independent FM transmitting and receiving circuit. Failure of any subcarrier has no effect on the operation of the other subchannels in use. This feature will also permit experimentation with one or several channels while other channels are being used on other projects. Also, special wide band channels may be used in conjunction with the standard channels and the only adverse result is a decrease in the maximum number of channels available.

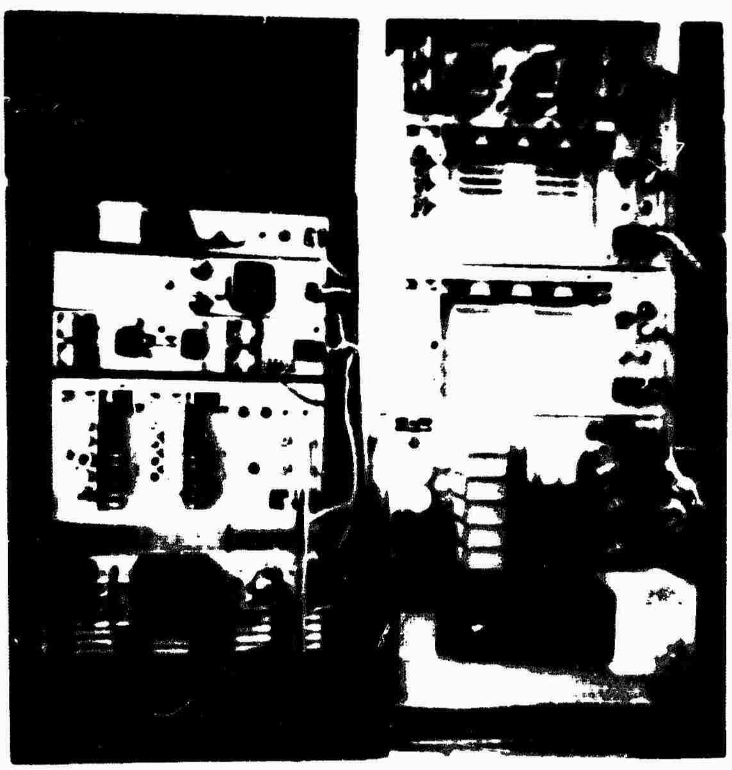


PLATE 4 TERMINAL EQUIPMENT

The subcarrier transmitter presently available operates on 660 kilocycles. It has an input limiter that controls the amplitude of the modulating voltage to prevent overmodulation. Figure 3 depicts the input limiter characteristic curve. The transmitter is frequency modulated by a reactance modulator tube connected directly across the oscillator tank circuit. The modulator tube plate current leads the oscillator voltage by 90 degrees, thus appearing as a capacitor to the oscillator circuit. Therefore, variation in amplitude of the modulator plate current causes a change in the frequency of oscillation. When an audio signal is applied to the modulator tube, the result is a change in oscillator frequency proportional to the amplitude of the audio signal. A change in grid bias of the modulator tube will also cause a change in frequency of the oscillator, thus allowing modulation to be accomplished by direct current voltage waveforms. Figure 4 pictures the reactance modulator operating characteristics.

The oscillator circuit used is a Colpitts type with the grid of the oscillator tube being grounded. This enables the reactive component of the modulator plate current to be coupled across the full oscillator tank circuit. This method of applying the modulation signal yields a high quality, low distortion FM signal.

The output amplifier presents a high impedance match to the oscillator, therefore it does not appreciably "load" the oscillator which is thus permitted to work at high efficiency and stability. The cathode circuit of this amplifier is made highly degenerative to

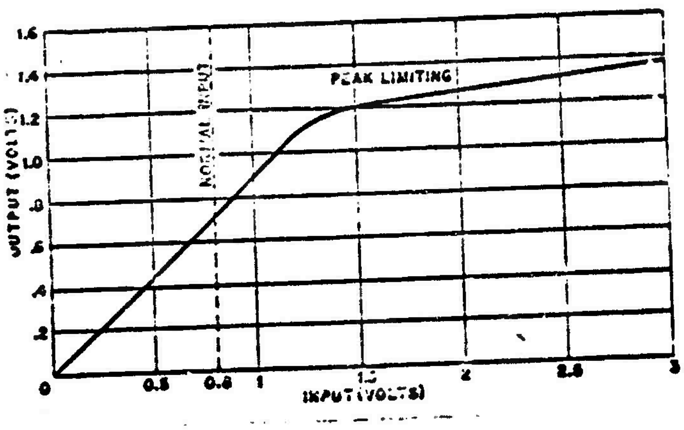


FIGURE 3

INPUT LIMITER CHARACTERISTIC CURVE

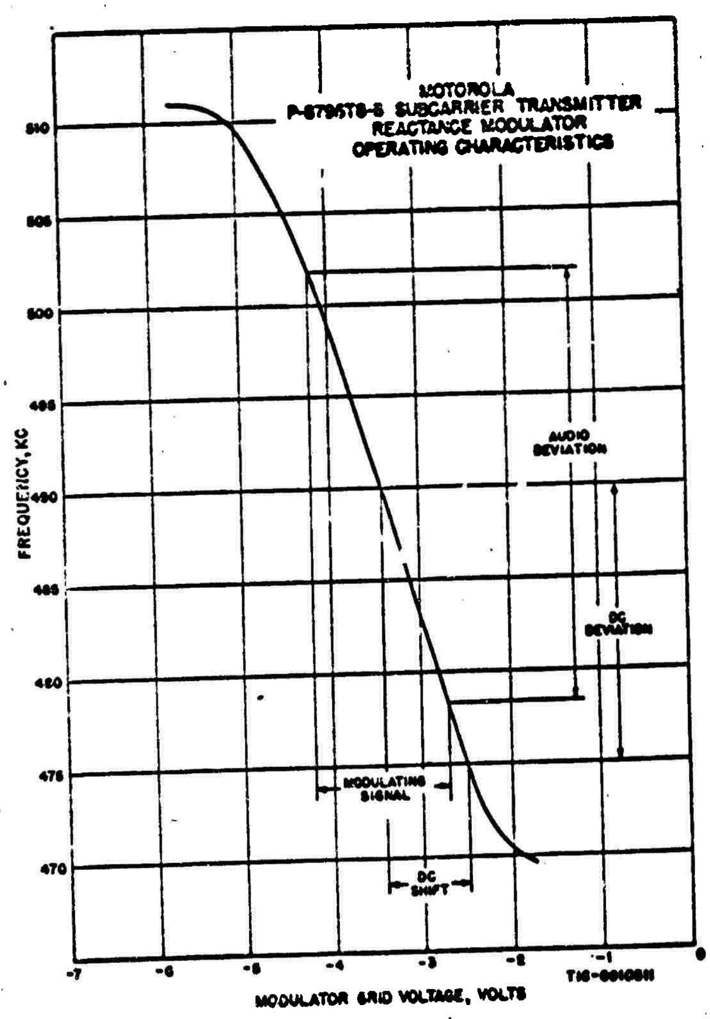


FIGURE 4

REACTANCE MODULATOR CHARACTERISTICS

control the amplitude of the output voltage. The cathode load also provides a source of phase-shift voltage for the transmitter. The output circuit for this stage is designed to pass only the fundamental frequencies of the output signal through use of a double tuned transformer. The outputs from all the subcarrier transmitters are combined and fed into the video amplifier of the microwave unit and then imposed as frequency modulation onto the microwave carrier frequency.

A subcarrier receiver obtains its input from the output of the microwave IF amplifier/discriminator. The particular unit installed operates at 660 kilocycles and consists primarily of an RF amplifier, limiter, discriminator, signal control, squelch control, and an audio output stage. Three tuned-transformer circuits in the RF amplifier and limiter stages make the unit highly receptive to only one channel frequency while rejecting all others.

The input circuit consists of a tuned RF transformer having a series resonant primary and a series resonant secondary circuit. Over-coupling of the transformer provides the proper bandpass. The series resonant primary circuit rejects all frequencies other than the one desired. A series resistor prevents loading of the video circuit to signals of the primary resonant frequencies, thereby preventing loss of signal amplitude as it is transmitted along the system.

The RF amplifier receives its signal from the input circuit and sends it to the limiter stage through a second double-tuned transformer. The limiter contains a third tuned transformer and provides

both grid and plate limiting. Grid limiting is obtained through the action of a parallel RC network, while reduced plate voltage produces plate limiting. As much as 50 percent amplitude modulation is reduced to 7.5 percent with an input signal of only 2.5 millivolts. The receiver selectivity is established by the three tuned transformers discussed above.

The output of the limiter is fed to a modified Foster Seeley Discriminator using germanium diode detector crystals. This circuit is designed to provide a wide, linear detector. The slope of the discriminator is adjusted to give a ten volt output signal with full DC deviation of the subcarrier transmitter. Since this deviation is dependent upon channel frequency, the discriminator is designed to provide the same output voltage for each channel. Figure 5 depicts the relationship between frequency input and voltage output for this discriminator.

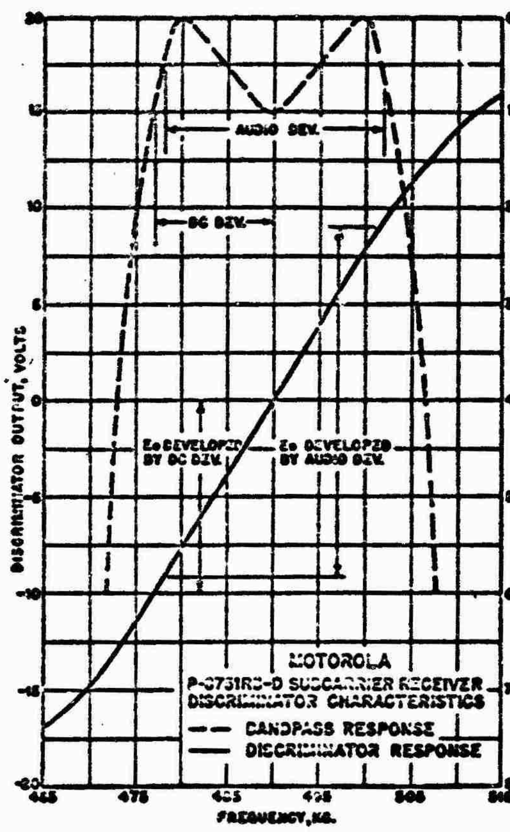


FIGURE 5

DISCRIMINATOR CHARACTERISTICS

TERMINAL EQUIPMENT

The voice terminals are designed to terminate the subcarrier transmitters and receivers for each of the many types of service available. All signals to the subcarrier transmitters and from the subcarrier receivers must pass through some type of termination equipment.

The Model P-6036, Dial Switchboard Voice Terminal, that is designed for two-wire, duplex operation of a telephone circuit when used in conjunction with a switchboard for dial trunk operation, is presently installed at one of the terminals. The other unit is terminated by a Model P-8764-A, Dial Telephone Voice Terminal. This equipment, as presently installed, provides a voice channel between the two terminal locations.

Various types of terminal equipment has been used on this kind of multiplex equipment. A few examples of the various services possible through use of correct terminations are:

1. Standard voice communication, two or four wire with ringing facilities.
2. Simplex private or party lines.
3. Duplex private or party lines.
4. Selective dial party lines.
5. Automatic switchboard terminations.
6. Dial telephone terminations.

7. Direct current (DC) control terminal for all types of desired DC functions.
8. Terminations for teletype, telemetering, and telegraph.
9. Mobile to microwave terminations.

This listing is intended to show what has been done with this type equipment and to give an indication of its capabilities, both present and latent.

CABLES

Coaxial cables having a nominal characteristic impedance of 75 ohms should be used between the subcarrier equipment and the microwave equipment. Two such cables are required at each microwave site, regardless of the number of subcarrier frequencies used. The output from all subcarrier transmitters at one location is fed simultaneously through one coaxial cable to the input of the video amplifier on the microwave equipment and one coaxial cable receives the output from the IF strip discriminator and simultaneously feeds all subcarrier receivers at that terminal. This is duplicated at the other microwave unit, so the system requires four such coaxial lines.

The output from the subcarrier receiver is carried through the interconnecting cable kit to its appropriate voice terminal. The input to the subcarrier transmitter is taken from this voice terminal through another pair in this same cable. These cables for the installed system are all installed and functioning.

The external connections to the voice terminal are normally made through 600-ohm phone lines. A telephone may be connected directly into the voice terminal.

DESIGN CONSIDERATIONS

The basic components were commercially manufactured by Motorola Incorporated and put in operable condition by effecting necessary repairs on a power supply, video amplifier, the metering section for one microwave RF unit, and a voice terminal. Following completion of these repairs, all the components in the system were aligned in accordance with the appropriate Motorola directives.

The design problems encountered were primarily of a system installation type. During the planning phase, intended use, hours of operation, terminal locations, and physical appearance were all considered. These problems will be discussed separately, however they are interwoven in that each has some influence on the others.

There were several reasons for the installation of this system. One predominate factor was to provide a two-way communication link between the Science Engineering Building and the Engineering Building over which various types of data can be transmitted simultaneously in both directions. One specific requirement was a system capable of accepting slow varying, direct current signal of several days duration generated by experiments conducted in the Engineering Building and transmitting them to the Science Engineering Building for recording by the data logger. This will be possible over the system however special control equipment and probably additional subcarrier channels will be required. Of the several microwave systems on hand, the type installed

was chosen because of its two-way capability and subcarrier equipment. Also, experiments in various methods of modulation and data transmission can be studied by using this system as a test vehicle. The requirement to accept a signal of several days duration dictates that continuous operation be possible. The basic equipment is capable of this and all the installations were made with this in mind.

Microwave terminal points were selected on the roofs of the two buildings of interest. Roof locations were chosen to enhance reliability of operation, afford added protection from pilfering, and simplify installation. The microwave transmission path thus achieved is sufficiently high above the terrain to preclude reception difficulties due to vehicular traffic or other obstructions of a temporary nature that would be more prevalent should the transmission path be near ground level. The location on the Science Engineering Building was chosen first and the position on the Engineering Building was partly determined to provide a transmission path straight from the face of the reflector on the Science Engineering Building.

The equipment on the Science Engineering Building was mounted inside a walled enclosure on a platform constructed for this project by Physical Plant personnel. This redwood platform was attached firmly to the base of the exterior wall and the equipment bolted to the platform. Although enclosure provided wind protection and enhanced the aesthetic quality of the installation, it also created a problem due to its position between the two terminal locations. Two methods to overcome this obstacle were considered. They were to mount the

parabolic reflector to the outside of the wall aimed in the horizontal plane toward the other location or to direct energy directly upward from the parabola to a screen situated above the wall and thus reflect the energy to the other location. The latter method was chosen.

The reflector was designed to be mounted on a tower with all braces being above the screen. This particular installation did not lend itself favorable to such a mounting technique, therefore a new system of braces and guys was designed to mount it on the enclosure wall. The height of this wall is 3.47 meters, so the lower edge of the signal beam crossing this obstruction was set at 3.7 meters to preclude adverse reaction. Plate 2 depicts this installation and Figure 6 shows the dimensions used.

The equipment on the roof of the Engineering Building was mounted on a redwood platform and guyed to four points along the parapets. The parabolic antenna was mounted on top of the outdoor housing and radiated its energy directly to the reflector on the Science Engineering Building. The parabola is afforded some weather protection by a hood mounted above it. The subcarrier equipment was installed in a room opening onto the roof of the building.

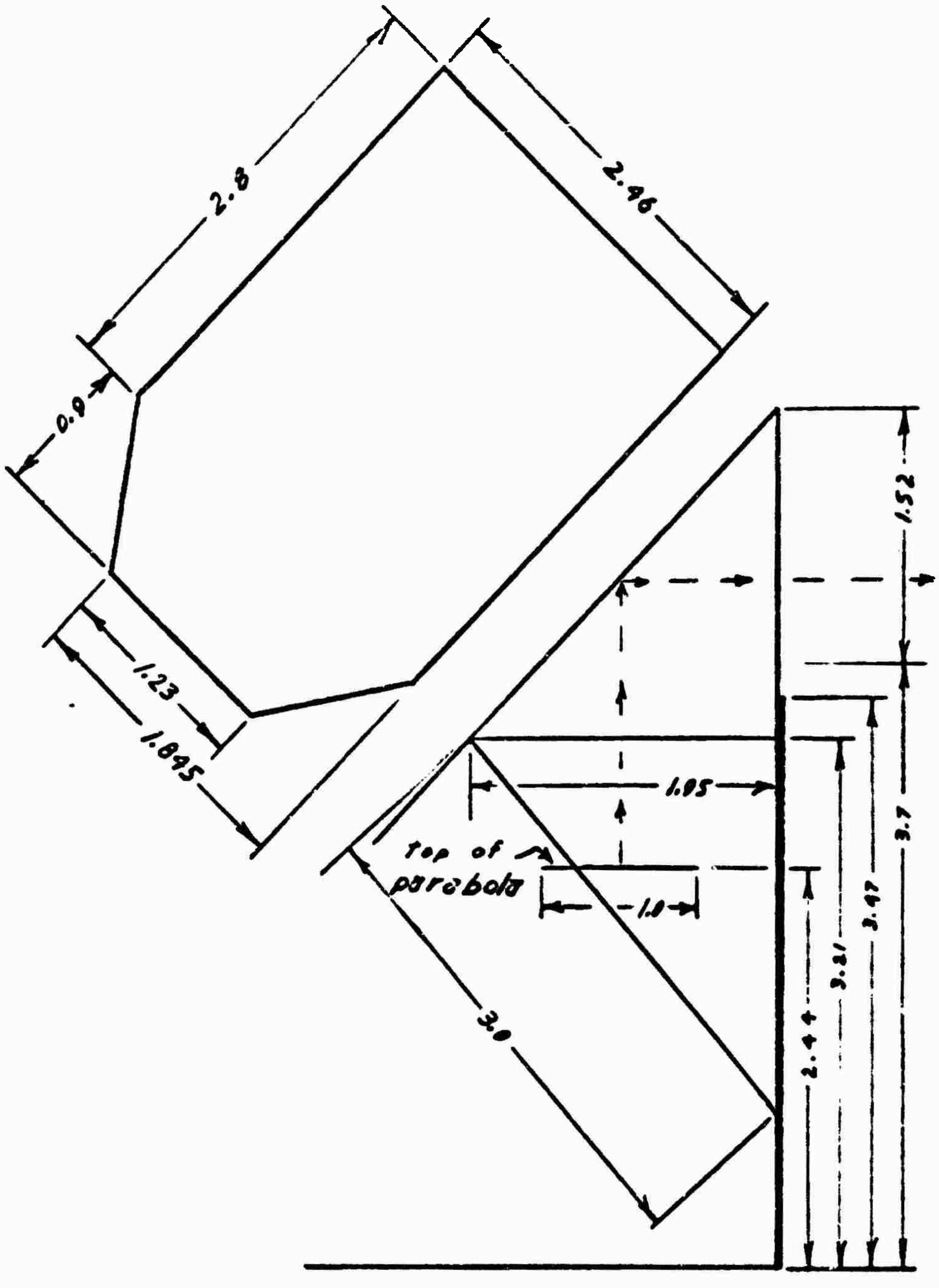


FIGURE 6 REFLECTOR INSTALLATION

Note: All dimensions in meters
Arrows denote ray trace

SYSTEM TESTING

Two methods were employed in testing this system. The first method was simply the use of telephone instruments connected to the voice terminals. The system was put in operation and voice communication was established between the two terminal locations. This circuit was very satisfactory for voice use.

This phase of testing verified that a high level of noise signal is in the FM subcarrier receiver output when the microwave local oscillator klystron is improperly tuned. Some checks to help determine if the local oscillator is operating properly are:

1. The microwave limiter current is high.
2. The microwave discriminator current is zero.
3. The local oscillator frequency test current is high.
4. The local oscillator power indication is high.

Another factor that will cause a high noise level is the failure of the microwave transmitter at the other terminal. However, the noise due to this difficulty is not as high as is the noise due to a maligned local oscillator.

The signalling circuits operated satisfactorily during these checks. One of the signalling circuits was designed and installed during this project. This circuit uses a DC buzzer that is controlled by the squelch and transmit circuits. The squelch relay is energized until a carrier is received from the appropriate subcarrier trans-

mitter at the other terminal location. It is then de-energized and remains in this state until that transmitter is shut off. The buzzer was connected into the circuit so that it would "buzz" whenever the squelch relay and the transmit control relay were both de-energized. The other circuit was included in the equipment. It generates an AC ringing current and activates a bell through very similiar control circuitry as that used to control the buzzer. The noise created by malalignment of the local oscillator klystron is sufficient to break the squelch circuit, thus activating the signalling devices.

A sine wave produced by a Heathkit generator was used for the signal during the other test. The input transformers and output transformers at both terminals were bypassed by the sine wave due to their having very low input/output impedances. The sine wave was fed into the voice terminal in the Science Engineering Building, thence through the subcarrier transmitter, the video amplifier and the microwave transmitter at that location. It was received at the other terminal, passed through all the receiving equipment and was delivered to the voice terminal. At this point it was shunted through a capacitor to the input portion of the terminal and then through the transmitting equipment back to the Science Engineering Building. It now went through the receiving equipment to the voice terminal from whence it originated, thus completing a round trip through the system. At this point the signal was observed on a Hewlett-Packard oscilloscope. A comparison was made with the output from the signal generator by using the dual trace provision and watching both waveforms simultaneously.

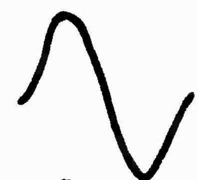
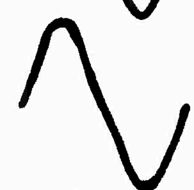
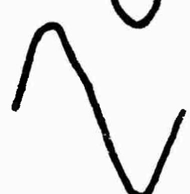
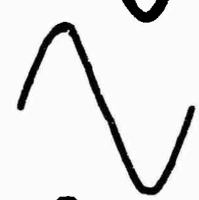
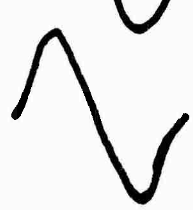
The output signal is presented in three different manners. Figure 7 shows the output wave form, voltage, and decibal level with zero db equal to one volt. The output wave form became a good sinusoid at about 1000 cps. Below this frequency, the amount and quality of distortion varied with frequency. Figure 8 shows a plot of frequency versus voltage output and Figure 9 depicts the output level expressed in db versus frequency. During all this testing the input voltage was kept constant at 4.0 volts, peak-to-peak. The wave form was a good sine wave at all inputs.

This testing confirmed that the system was operational, thus completing the installation project.

FIGURE 7

OUTPUT WAVE FORM

All inputs: 4.0 volts peak-to-peak sinusoid
db reference: 0 db=1 volt

freq. (cps)	V out pk-pk	db		freq. (cps)	V out pk-pk	db	
40	-		-	600	11.0	20.8	
50	1.2	1.6		1000	12.0	21.7	
70	3.6	11.0		1200	13.5	22.6	
100	9.0	19.1		1800	18.0	25.1	
150	17.5	24.84		3000	11.0	20.8	
200	17.5	24.84		3500	4.8	13.7	
250	17.0	24.6		4000	2.0	6.04	
400	12.0	21.7		4500	1.0	0	

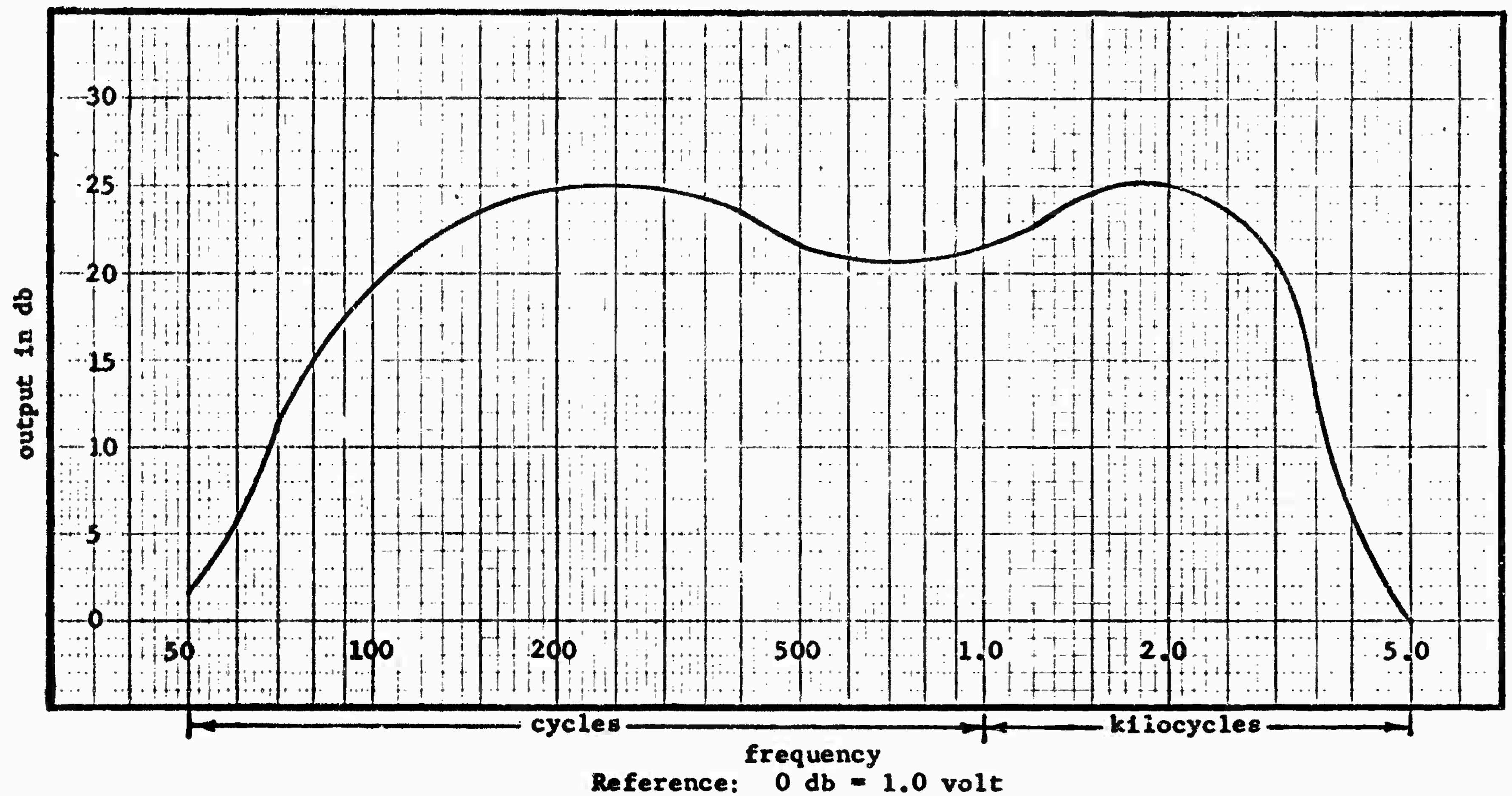


FIGURE 9 NORMALIZED OUTPUT IN DB VERSUS FREQUENCY

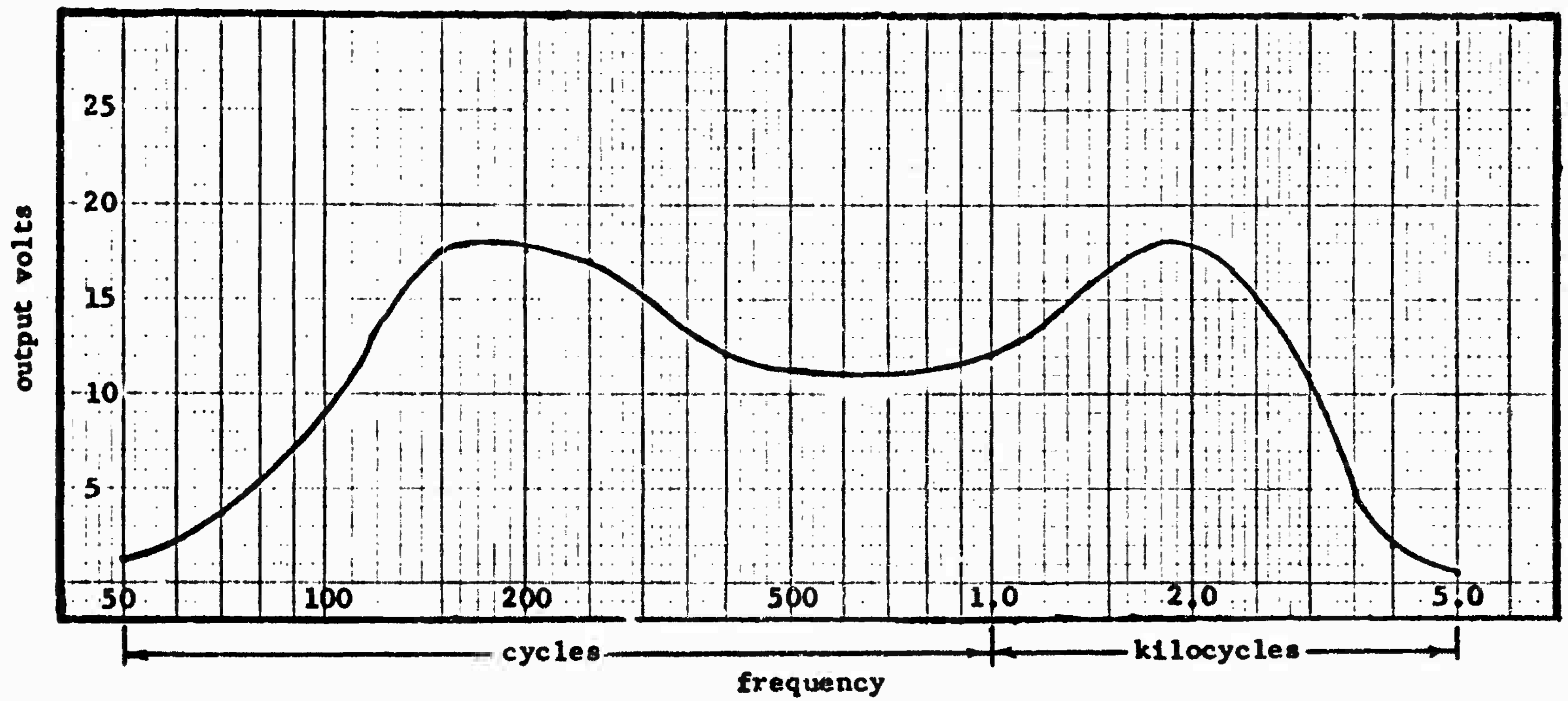


FIGURE 8 OUTPUT VOLTS VERSUS FREQUENCY

MODIFICATIONS

The microwave unit operates on 6415 megacycles and 6295 megacycles. There is an amateur radio frequency band from 5650 to 5925 megacycles. The waveguide dimensions are 1.372 by 0.62 inches and has a lower cutoff frequency of 4301 megacycles. It may be possible to tune the pre-selector cavities to the amateur frequencies and by changing klystrons, operate this equipment as a part of W5YM.

The subcarrier receivers and transmitters are frequency modulated. This is not necessarily a requirement so far as the microwave portion is concerned, so other types of receivers and transmitters can be built and tested over this system.

The present reactance modulator was intended primarily for audio signals, however, DC can be used and this feature may be exploited.

The microwave system will accept a direct television video input, therefore any other information requiring a wide bandwidth (30 cycles to 4.5 megacycles) is acceptable.

To permit a voice channel in addition to the subcarrier channel presently available, a low pass filter with cutoff at 3000 cps could be used to permit direct modulation of the klystron with audio and not interfere with the subcarrier operation.

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